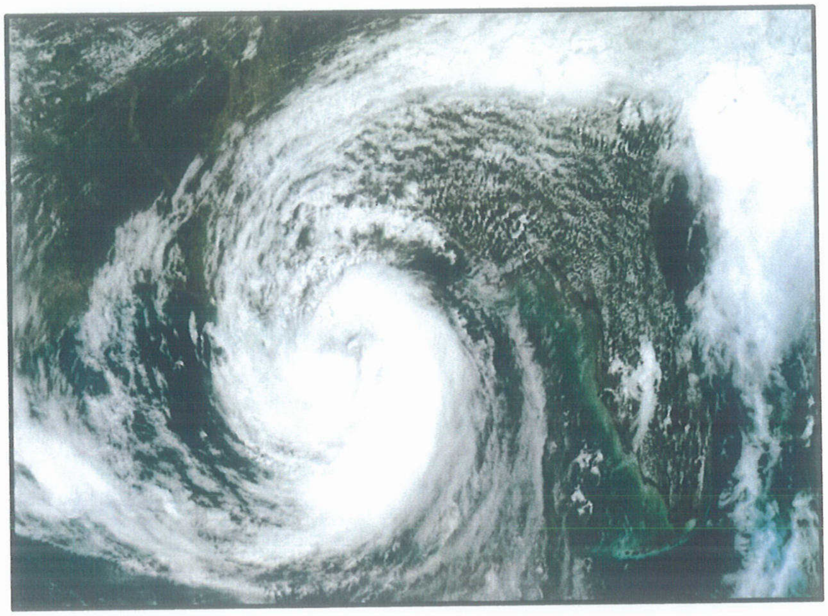
Hurricane Isaac With and Without 2012 100-year HSDRRS Evaluation



Final Report
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EXHIBIT
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EXECUTIVE SUMMARY

SIGNIFICANT FINDINGS

- According to the Saffir-Simpson Hurricane Wind Scale, Isaac was a minimal Category 1 hurricane; however, the storm produced 45 hours of tropical force winds from the south and south east on a track west of New Orleans, LA. This wind and track, combined with slow forward motion, large maximum wind radius, and intense rainfall produced high storm surges and water levels. The resulting inundation in communities outside the greater New Orleans Hurricane and Storm Damage Risk Reduction System (HSDRRS) demonstrates that every hurricane is unique and that the Saffir-Simpson Scale should not be used as the sole predictor of inundation risk.

- High water marks show that there were only a few places that the old system would have been overtopped during Hurricane Isaac; thus the old system would have displaced about the same amount of water as the new system and the HSDRSS could not have significantly influenced inundation at communities external to the system.

- The Hurricane Isaac surge modeling produced water level differences between the with and without 2012 100-year HSDRRS conditions that were consistent with and support the previous modeling used in the design and environmental assessment of the HSDRRS.

- The Hurricane Isaac model simulations showed that any changes of water level due to the 2012 100-year HSDRRS system are 0.4 feet or less at communities outside the system. Changes in water level of this magnitude are less than model precision.

- Potential changes in water level from previous modeling were communicated to the general public in Individual Environmental Reports as well as public meetings regarding the HSDRRS held between 2007 and 2012.

- These increased water levels due to the 100-year HSDRRS do not explain the many feet of flooding that several communities outside of the system experienced during Hurricane Isaac. This flooding was caused by intense and long duration storm surge due to the long duration of tropical force winds, which, in some cases were aggravated by extreme local rainfall.

Introduction

On 29 August 2012, Hurricane Isaac made landfall along and impacted the Louisiana and Mississippi coastline. Impacts to the coastal Louisiana area, including New Orleans and surrounding communities, were considerable. The 2012 greater New Orleans area 100-year Hurricane and Storm Damage Risk Reduction System (100-year HSDRRS) performed to expectations in preventing the Hurricane Isaac storm surge from inundating the areas within the system. However, substantial flooding did occur in areas without federal levee systems, including, but not limited to Slidell, Mandeville, Madisonville, LaPlace, Braithwaite, Lafitte and others.

During the design of the 100-year HSDRRS, multiple sensitivity analyses were conducted to describe the potential effects of the system on storm surge elevations outside of the system. These modeling efforts predicted that the 100-year HSDRRS would increase the estimated peak water levels generally less than 0.2 feet in communities outside the HSDRRS. However, in response to the substantial flooding outside of the HSDRRS, concerns were raised regarding the effects of the 100-year HSDRRS during Hurricane Isaac on areas outside the system. Local and state officials requested an analysis to assess the effect of the 100-year HSDRRS on certain areas outside the system as a result of Hurricane Isaac.

The analyses contained in this assessment were conducted by a team consisting of personnel from the U.S. Army Corps of Engineers' New Orleans District, Mississippi Valley Division, and Engineering Research and Development Center, and the National Oceanic and Atmospheric Administration's National Weather Service. Data were compiled from the Corps of Engineers New Orleans District, the National Oceanic and Atmospheric Administration's National Hurricane Center, National Weather Service River Forecast Center in Slidell, LA, National Data Buoy Center, and National Ocean Service, the United States Geological Survey, and the State of Louisiana.

Assessment Purpose

This assessment was developed and conducted to answer one primary question:

Did construction of the 100-year HSDRRS have a measurable effect on areas outside the system inundated by Hurricane Isaac?

Assessment Overview

To examine the question on the impact of HSDRRS, this assessment focused on:

1. Defining Hurricane Isaac's meteorological statistics and surge propagation, and how they contributed to inundation outside the 100-year HSDRRS;

2. Previous Corps of Engineers analyses regarding effects from the 100-year HSDRRS;

3. Identifying the differences in surge conditions between the "With" and "Without" 2012 100-year HSDRRS conditions specifically for Isaac.

The data, methodologies and analyses supporting the assessment findings are organized by chapter. Refer to specific chapters for detailed discussions. Chapter summaries are provided below:

Chapter 1: Introduction - This chapter provides the purpose, scope and limitations of the assessment. A summary of assessment limitations are provided below, after these chapter summaries.

Chapter 2: Summary of 100-Year HSDRRS Conditions - This chapter provides a description of the "With" and "Without" 2012 100-year HSDRRS conditions and the comparative analysis between the two conditions. The footprint of the two conditions is, with the exception of some project features, essentially along the same alignment, although the HSDRRS project is higher in elevation and has a wider levee footprint. However, high water marks from Hurricane Isaac generally indicate that the storm would not have overtopped the pre- 2012 HSDRRS system, except in a few areas identified, and did not overtop the 2012 100-year HSDRRS system.

Chapter 3: Hurricane Isaac Event Overview - This chapter provides a detailed synopsis of the meteorological characteristics of Hurricane Isaac, including analysis of winds, wind directions, surge levels, storm track and duration and wave data. According to the Saffir-Simpson Hurricane Wind Scale, Isaac was a minimal Category 1 hurricane, reaching maximum sustained wind speeds of approximately 80 miles per hour immediately before landfall. However, the storm's ability to move water into the low-lying areas of coastal Louisiana and Mississippi was much greater than this wind speed suggests. The long duration of tropical force winds, the storm track and slow forward motion, the storm size, the high tide conditions and significant rainfall occurring at the same time as the maximum storm surge, resulted in large amounts of water being pushed into the coastal areas of the northern Gulf. In many cases, water levels exceeded those from more intense storms such as Hurricanes Katrina and Gustav.

Chapter 4: Comparison of System Characteristics and Performance - This chapter summarizes the performance of the 2012 100-year HSDRRS during Hurricane Isaac based on gage data, high water marks, and photographs taken during the damage assessment site visits. Based on analysis of the collected data, there is no indication of wave overtopping or surge overflow along the 2012 100-year HSDRRS, including the Mississippi River Levees between river mile 80 and 130. High water marks show that there were only a few places that the old system would have been overtopped during Hurricane Isaac; thus the old system would have displaced about the same amount of water as the new system and the HSDRSS could not have significantly influenced inundation at communities external to the system.

Chapter 5: Prior Evaluations of HSDRRS Performance - This chapter provides a synopsis of analyses on the potential impact of the HSDRRS on areas outside the system that were conducted during the development and design of the HSDRRS and communicated to the public through Individual Environmental Reports and public meetings The model generally predicted increases in estimated peak water levels of less than 0.2 feet at communities outside the HSDRRS, although it produced about 0.9 feet of increase in the vicinity of the Caernarvon Floodwall near Braithwaite.

Chapters 6: Hurricane Isaac Model Simulations - This chapter documents model simulations of Hurricane Isaac with and without the 2012 100-year HSDRRS in place. A preliminary assessment of the model made through comparison of measured data to model predictions indicates the model does reasonably well in simulating Hurricane Isaac across southeast Louisiana and Mississippi. The greatest differences were in Breton Sound. The model over predicts water levels at the upper end of Caernarvon marsh near Braithwaite by as much as approximately 3 feet. In general, model results indicate that water levels are relatively higher in Breton Sound and lower in Lake Pontchartrain with the HSDRRS in place. The differences between the with and without 2012 100-year HSDRRS condition are generally 0.2 feet or less across southeast Louisiana and Mississippi. An overview of the differences produced by the model are provided in Figure i.1. A positive difference indicates that water levels are higher with the 2012 100-year HSDRRS in place, negative values indicate lower predicted water levels with the 2012 100-year HSDRRS in place. The dark blue regions represent flooding within polders that was prevented by the HSDRRS. The largest difference outside of polders shown in the figure is an increase in water level of approximately 0.8 feet in the immediate vicinity of the Western Closure Complex in an uninhabitated area. Increases in water level outside the immediate vicinity of the West Closure Complex diminish to 0.4 feet near the communities of Crown Point, 0.2 feet at Jean Lafitte and less than 0.1 feet in the majority of the Barataria basin.

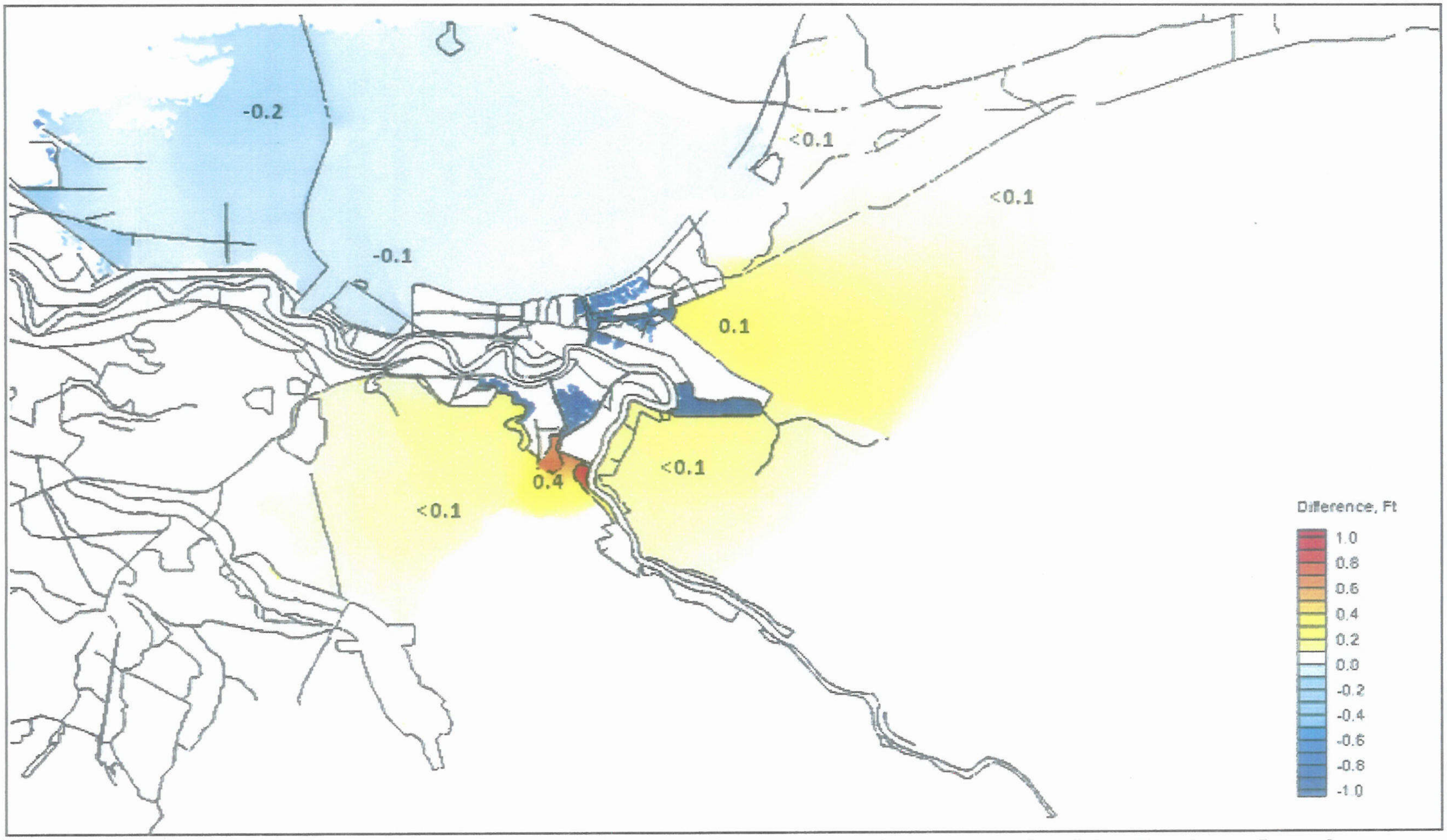

Figure i.1. Results of ADCIRC model simulation showing difference in maximum water level for Hurricane Isaac between with and without 2012 100-Year HSDRRS

Chapter 7: Detailed Evaluations - This chapter provides a summary of the hydrodynamic model results for certain areas outside the 2012 100-year HSDRRS adversely impacted by Hurricane Isaac. Lake Pontchartrain Northshore & West Shore: Peak water levels would decrease by approximately 0.1 feet. Total rainfall was approximately 10 to 15 inches. Plaquemines Parish East Bank: Peak water level would increase by approximately 0.3 feet in the immediate vicinity of Caernarvon floodwall and 0.1 or less throughout the area. Total rainfall was approximately 11 inches. High water marks indicated peak stage of approximately 13.8 feet. West Closure Complex (WCC) & Eastern Tie-In: Peak water level would increase by approximately 0.8 feet in the immediate vicinity of WCC; 0.4 feet near Crown Point; 0.2 feet at Jean Lafitte and 0.1 or less in the majority of Barataria basin. Total rainfall was approximately 10 to 11 inches. High water marks indicated peak stage of approximately 5.0 feet. near WCC. Mississippi Gulf Coast: Peak water level would increase by less than 0.1 feet in the Mississippi Gulf Coast area. Total rainfall was approximately 10 inches (Gulfport) to 22 inches (Pascagoula). Gage indicated peak stage of approximately 9 feet in the Bay St. Louis area. It should be noted that these areas were selected as representative areas to assess the impact of the 2012 100-year HSDRRS; it is not an exhaustive investigation of all areas that were subject to inundation.

Chapter 8: Summary of Findings – This chapter summarizes the findings of the assessment.

Assessment Limitations

The analyses and findings contained in this assessment utilized only available data. Specific data limitations were:

- All gage data are considered provisional, subject to revision.
- High water marks were collected only in accessible locations where right of entry was not required.
- Data related to hurricane characteristics, such as track, wind speed, radius to maximum winds, central pressure, and other parameters were compiled from available data.
- Available hurricane surge models were utilized. The model grids were updated (including local levees in the existing models) using 2012 Light Detection and Ranging (LIDAR) information and as-built survey

information to describe the 2012 100-year HSDRRS. The grids have not been updated to include new local features such as Mardi Gras Pass.

- Rainfall modeling was limited:
  - St. John the Baptist Parish: Where existing models were available, these models were used to perform an initial assessment of the direct rainfall impacts.
  - Western Closure Complex: Previous rainfall model results were considered.
  - Remaining Areas: A qualitative assessment was performed using rainfall and gage data.

- This assessment does not include analyses on economic damages or potential solutions to the flooding.

Conclusion

Did construction of the 100-year HSDRRS have a measurable effect on areas outside the system flooded by Hurricane Isaac?

Most of the HSDRRS system was built on the same alignment as the old hurricane protection system. In all but three areas, the high water marks were below the elevation of the old system. In general, model results indicate that water levels were relatively higher in Breton Sound and lower in Lake Pontchartrain with the HSDRRS in place. The Hurricane Isaac model simulations showed that any changes of water level due to the 2012 100-year HSDRRS system are 0.4 feet or less at communities outside the system. Changes in water level of this magnitude are less than model precision. These findings are consistent with previous modeling of HSDRRS impacts during design and construction of the project and previously communicated to the public.

Hurricane Isaac With & Without 2012 100-Year Hurricane Storm Damage Risk Reduction System Evaluation

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APPENDICES (VOLUME II)

LIST OF ACRONYMS

ADCIRC	Advanced Circulation Model
CRMS	Coastal Reference Monitoring System
FEMA	Federal Emergency Management Agency
GIWW	Gulf Intracoastal Water Way
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center – River Analysis System
HSDRRS	Hurricane & Storm Damage Risk Reduction System
IER	Interim Environmental Report
IHNC	Inner Harbor Navigation Canal, Inner Harbor Navigation Canal Surge Barrier
IPET	Interagency Performance Evaluation Team
JPM-OS	Joint Probability Method – Optimal Sampling
LACPR	Louisiana Coastal Restoration and Protection study
LPV	Lake Pontchartrain & Vicinity Hurricane & Storm Damage Risk Reduction Project
LST	Local Standard Time
MRGO	Mississippi River Gulf Outlet
MRL	Mississippi River Levee
NAVD	North American Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
QPE	Quantitative Precipitation Estimate
SELA	South East Louisiana Flood Control Project
STWAVE	Steady State Spectral Wave Model
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
UTC	Coordinated Universal Time (Greenwich Mean Time, GMT)
WAM	Wave Prediction Model
WBV	West Bank & Vicinity Hurricane & Storm Damage Risk Reduction Project
WCC	Western Closure Complex

1.0 INTRODUCTION

Purpose and Scope

Hurricane Isaac's impacts to the coastal Louisiana and Mississippi area were considerable. The greater New Orleans area 100-year Hurricane & Storm Damage Risk Reduction System performed to expectations in preventing the Hurricane Isaac storm surge from inundating the areas within its system. However, substantial flooding did occur in areas without federal levee systems, including, but not limited to Slidell, Mandeville, Madisonville, LaPlace, Braithwaite, and Lafitte and others. As this was the first major test of the 100-year HSDRRS, some have raised concerns regarding the effects of the 100-year HSDRRS during Hurricane Isaac on areas outside the system. Local and state officials have requested an analysis to assess the role of the 100-year HSDRRS during Hurricane Isaac on the areas outside the system. Figures 1.1 and 1.2 provide maps of the study area to help orient the reader to the communities and major geographic features referenced in this report.

This assessment was developed and conducted to answer one primary question:

Did construction of the 100-year HSDRRS have a measurable effect on areas outside the system flooded by Hurricane Isaac?

To answer this question, the following were examined:

- Hurricane Isaac's meteorological statistics and surge propagation, and how they contributed to flooding outside the 100-year HSDRRS
- Previous Corps of Engineers analyses regarding effects from the 100-year HSDRRS
- What, if any, differences in surge conditions are identifiable between the with and without 100-year HSDRRS (2012 conditions) specifically for Isaac?

Most of the new 100-year HSDRRS was built on the same alignment as the old system. During the design of the 100-year HSDRRS, extensive modeling and analysis was performed during the design phase of the system to determine what effect, if any, the system would have on other areas. Public meetings were held across the area at which the modeling and analyses were discussed. Environmental documentation included discussions on effects of the 100-year HSDRRS on adjacent areas.

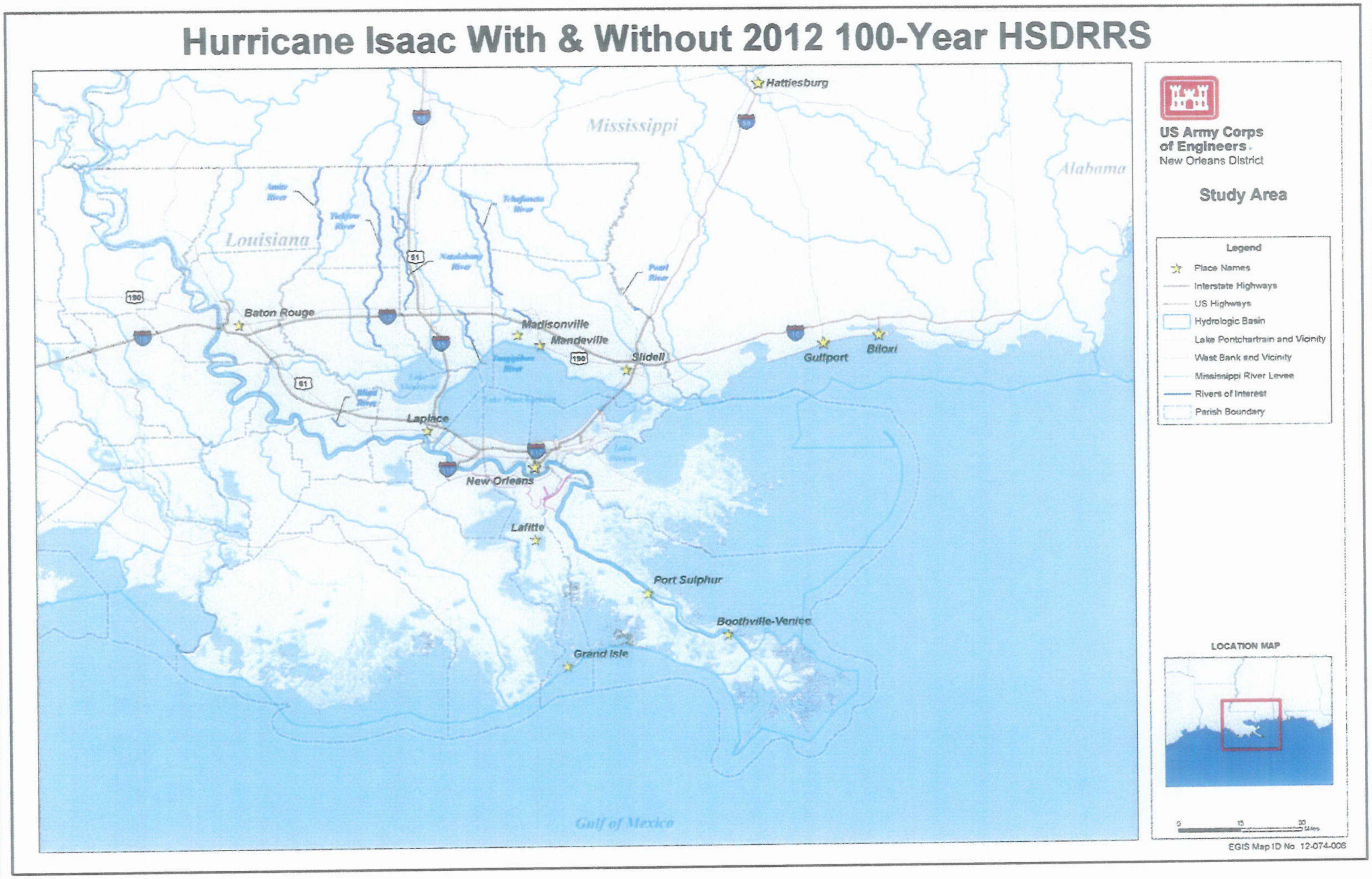

Figure 1.1 Vicinity Map of study area including southeast Louisiana and the Mississippi Gulf Coast.

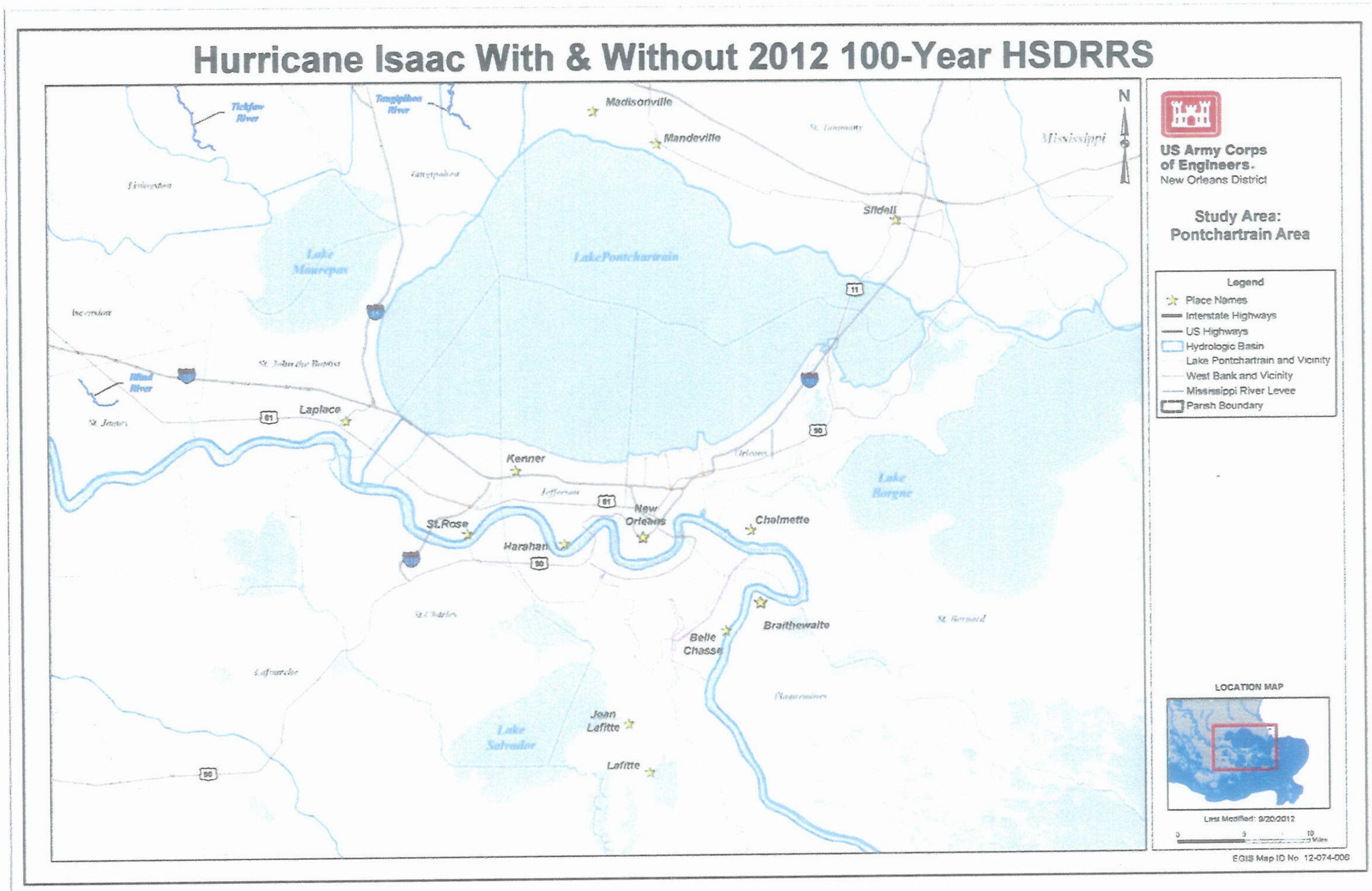

Figure 1.2 Southeastern Louisiana study area including major geographic features and communities referenced in report

This effort integrates the aforementioned work with an assessment of available storm data and modeling of Hurricane Isaac for two conditions: without the 100-year HSDRRS and with the 2012 100-year HSDRRS features. The scope consists of several parts:

- Compilation and analysis of available Hurricane Isaac storm information, meteorological, stage, and high water mark data
- Comparison of with and without 2012 100-year HSDRRS characteristics and performance
- Qualitative analysis and review of previous modeling and analyses
- ADCIRC Isaac model simulations for with and without-HSDRRS conditions.
- Evaluation of specific areas outside the 100-year HSDRRS where flooding occurred. It should be noted that these areas were selected as representative areas to assess the impact of the 100-year HSDRRS; it is not an exhaustive investigation of all areas that were subject to inundation.

The work has been conducted by a team consisting of personnel from the Corps of Engineers' New Orleans District, Mississippi Valley Division, and Engineering Research and Development Center, and the National Oceanic and Atmospheric Administration's National Weather Service. Data were compiled from the Corps of Engineers New Orleans District, the National Oceanic and Atmospheric Administration's National Hurricane Center, National Weather Service River Forecast Center in Slidell, LA, National Data Buoy Center, and National Ocean Service, the United States Geological Survey, and the State of Louisiana. The Water Institute of the Gulf and the Southeast Louisiana Flood Protection Authority – East (SLFPA-East) has performed an over the shoulder review of the data, modeling, and analyses, and provided comments which are provided in Appendix D.

This report presents the findings of these analyses. Quality control and agency technical review have been conducted on the findings. Independent external peer review has been scheduled; the results of the review will be appended to this document upon completion.

Limits of Investigation

In the interest of providing a timely assessment, there are several limitations regarding the data used and the analysis performed.

- All gage data are considered provisional, subject to revision.

- High water marks were collected only in accessible locations where right of entry was not required.

- Data related to hurricane characteristics, such as track, wind speed, radius to maximum winds, central pressure, and other parameters were compiled from available data.

- Available hurricane surge models were utilized. The model grids were updated (including local levees in the existing models) using 2012 Light Detection and Ranging (LiDAR) information and as-built survey information to describe the 2012 100-year HSDRRS. The grids have not been updated to include new local features.

- Rainfall-runoff analysis and modeling was limited:

    - St. John the Baptist Parish: Where existing models were available, these models were used to perform an initial assessment of the direct rainfall impacts.
    - Western Closure Complex: Previous rainfall model results were considered.
    - Remaining Areas: A qualitative assessment was performed using rainfall and gage data.

- This assessment does not include analyses on economic damages or potential solutions to the flooding.

Data related to hurricane characteristics, such as track, wind speed, radius to maximum winds, central pressure, and other parameters have been compiled from available data. The referred data sources are the same as those listed in, for example, Cardone and Cox 2009 and include gridded and image fields of marine surface wind composites from the Hurricane Research Division (HWind). For a hindcast of a storm, winds are typically constructed by an expert meteorologist through a careful and time consuming process of assimilating best available data collected during the storm into the calculation of the wind and pressure fields, see Cardone and Cox 2009, Cox et al. 1998 and Powell et al, 2010 for detailed descriptions of this process including a discussion of the tropical planetary boundary layer model (PBL). In summarizing this process, the hindcast approach used to produce the model inputs as applied in this study consists of four basic steps and follows from the description of the PBL hindcast section in Cardone and Cox 2009.

First, all relevant meteorological data is assembled from in-situ sources, reconnaissance aircraft and meteorological satellites. Second, the storm parameters required to initialize a tropical planetary boundary (PBL) model are determined using all available data. The PBL output is then compared to available in situ data, iterated if required, then blended within a basin-wide synoptic wind and pressure field. Finally, the wind and pressure fields are adopted on a working grid to be applied by the wave and surge models.
The National Hurricane Center has not completed an analysis of the storm data collected during Hurricane Isaac, nor have they completed a tropical cyclone report. The National Hurricane Center usually prepares these reports after hurricane season; a report on Hurricane Isaac is expected to be available in early 2013.

The wind product used in the simulations was constructed in accordance with the procedures outlined in Cardone and Cox 2009. Figure 1 shows the relationship between the ADCIRC computational domain and the PBL domain. Wind and pressure fields were provide in a rectangular domain that completely encompasses the Gulf of Mexico. The domain is between longitudes -98.0 degrees west to -80.0 degrees west and between latitudes 18.0 degrees north and 32.0 degrees north. The winds and pressures are specified on a regular grid within this domain with grid cells spaced 0.05 degrees apart. The surge model ADCIRC linearly interpolates the regular gridded data unto its unstructured computational nodes. Any ADCIRC node that lies outside the PBL domain has a wind velocity of zero meters per second and a pressure value set to a standard background value of 1013.0 MB (milibars). The wind and pressure values were specified every 15 minutes beginning on August 24, 2012 at 1200 hrs UTC and going through August 31, 2012 1800 hours UTC. The beginning time was just prior to the center of Hurricane Isaac entering the Gulf of Mexico and continuing more than two days after making landfall.

Figure 2.3. Map showing the extents of the ADCIRC computational domain and the area of coverage for the wind and pressure fields.

As part of the testing of available wind/pressure products for use with the surge and wave models, the HWinds products as available from the Hurricane Research Division were evaluated. However, without properly blending these HWinds into a larger background meteorological field, a process described in Cardone and Cox 2009 and Powell et al 2010 among others, the raw HWinds products are typically not suitable for driving accurate surge responses. For Hurricane Isaac, driving ADCIRC with the HWinds gridded data consistently produced lower than observed surges (at times more than 1 foot lower) at most of the NOAA buoys in the area of interest. The HWinds products are available beginning August 21, 2012 at 1930 hours UTC and ending August 29, 2012 at 1930 hours UTC. The frequency of the data varies between 6 hour intervals at the onset of the data and transitions to 3 hour intervals at 0130 hours UTC on August 26, 2012. The Marine gridded HWinds data is on a moving grid that is centered on the center of the storm. Thus as the storm moves so does the area over which the winds are available. Figure 2 shows a map of the ADCIRC computational domain in relation to several of the moving grid domains used in the HWinds product as the storm moves. Just like in the PBL model case, ADCIRC linearly interpolates the regular gridded data onto its unstructured computational nodes. Any ADCIRC node that is outside of a gridded box has the wind values set to zero meters per second and a constant background pressure of 1013 MB. As can be seen from the red outlined box in Figure 2, the area of interest for this study does not begin to experience wind and pressure effects from the storm until August 27, 2012 at 1930 hours UTC. Furthermore, at no time does the entire Gulf experience computationally the full effects of the entire storm forcing due to the limited domain sizes of the HWinds gridded data, thus limiting the impacts of surge buildup from the entire Gulf due to the generally northwesterly background winds. Another issue is that the HWinds data ends less than a day after landfall even though the storm had virtually stalled in the area and continued to contribute to higher than normal water levels in the area of interest to this study beyond August 31, 2012.

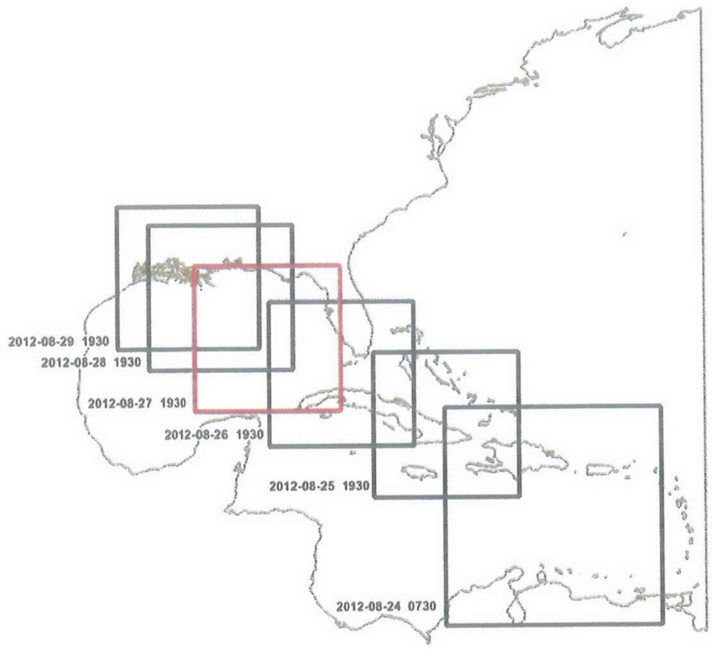

Figure 1.4. Map showing the ADCIRC computational domain along with H*Wind domains of coverage for several dates corresponding to Hurricane Isaac.

This assessment considers the 2012 100-year HSDRRS as it existed at the time of Hurricane Isaac. Although 100-year level of risk reduction has been achieved, the HSDRRS is not complete. Any incomplete features were not incorporated into the assessment.

Because the purpose of the Hurricane Isaac modeling investigation was to assess possible differences in surge related to the 100-year HSDRRS, and resulting specifically from Hurricane Isaac, the "without HSDRRS" condition applied only to features of the 2012 100-year HSDRR System. Other landscape features represented in the model were identical for the with and without 2012 100-year HSDRRS simulations.

Available hurricane surge models have been utilized. The model grids have been updated using 2012 LiDAR information and as-built survey information to describe the 2012 100-year HSDRRS. Local levees, such as the

Braithwaite levee that are in existing models, have been updated based on 2012 LiDAR information. The grids have not been updated to include new local features.

Rainfall modeling has been limited; for St. John the Baptist Parish, where existing models were available, these models were used to perform a preliminary assessment of the direct rainfall impacts. For the West Closure Complex, previous rainfall model results were considered. For the remaining areas a qualitative assessment was performed using rainfall and gage data.

This assessment is limited to answering the questions listed in the scope section. This assessment does not address economic damages or potential solutions to the flooding.

References

Cardone, V.J. and A. T. Cox, 2009, Tropical cyclone wind field forcing for surge models: critical issues and sensitivities. Nat. Hazards, 51, 29-47.

Cox, A.T. and V.J. Cardone, 2007, Workstation assisted specification of tropical cyclone parameters from archived or real time meteorological measurements. 10th international workshop on wave hindcasting and forecasting and coastal hazard symposium, North Shore, Hawaii, 11–16 November 2007.

Powell, M.D., S. Murillo, P. Dodge, E. Uhlhorn, J. Gamache, V. Cardone, A. Cox, S. Otero, N. Carrasco, B. Annane, R. St. Fleur, 2010, Reconstruction of Hurricane Katrina's wind fields for storm surge and wave hindcasting. Ocean Engineering, 37(1), 26-36.

2.0 SUMMARY OF 100-YEAR HSDRRS CONDITIONS

Chapter Summary

This chapter describes with and without 2012 100-year HSDRRS condition. While the without 100-year HSDRRS condition captures the system as it existed prior to construction of the 100-year HSDRRS, the 2012 100-year HSDRRS condition includes increased levee and floodwall heights around the system as well as additional features IHNC Surge Barrier, Seabrook Gate Complex, Outfall Canal interim closure structures, Caernarvon floodwall and gate, Eastern Tie-In, Harvey-Algiers system with the West Closure Complex, Bayou Segnette Complex, and Western Tie-In. The Harvey Sector Gate which was completed after Hurricane Katrina, is considered part of the without 100-year HSDRRS conditions.

The majority of the 2012 100-year HSDRRS levees, floodwalls, and structures were constructed generally following the existing alignment of the Lake Pontchartrain & Vicinity (LPV) and West Bank & Vicinity (WBV) features that comprise the without 2012 100-year HSDRRS condition.

New features that have been added and features at locations where the existing alignment has been modified are discussed in detail. Additional discussions are included regarding the features of the 100-year HSDRRS under construction that were not complete at the time Hurricane Isaac made landfall and for which temporary risk reduction measures were put in place.

Without 2012 100-year HSDRRS Condition

The without 2012 100-year HSDRRS condition is comprised of LPV and WBV levees, floodwalls, and structures that were in place prior to the construction of the 100-year HSDRRS. The height of the levees and floodwalls are shown on Plate 1.

Several survey datasets were utilized to develop the without 2012 100-year HSDRRS condition and are listed in Table 2.1. Surveys were taken between 2004 and 2012.

Table 2.1 – Surveys used to determine without 2012 100-year HSDRRS elevations

Survey Job Title
Mississippi River Levee Profiles (WEST PONTCHARTRAIN LEVEE DISTRICT)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (PLAQUEMINES) (ARCADIS)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (ST BERNARD) (ARCADIS)
New Orleans District National Levee Foot Print Data Base Surveys (WEST PLAQUEMINES)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (EAST JEFFERSON) (HTNB)
2006 LEVEE/FLOODWALL ASSESSMENT HPS(NEW ORLEANS EAST)(HTNB)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (WEST OF ALGIERS) (C&C Technologies)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (ST CHARLES) (BFM)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (NEW ORLEANS) (ARCADIS)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (WESTWEGO) (C&;C Technologies)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (EAST OF ALGIERS) (C&C Technologies)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (CATAOUATCHE) (C&C Technologies)
HSDRRS Line of Protection Survey (MRL)
New Orleans District National Levee Foot Print Data Base Surveys (BELLE CHASSE)
New Orleans District National Levee Foot Print Data Base Surveys (MRL ST JUDE TO VENICE)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (PLAQUEMINES) (ARCADIS)
Precision Airborne LiDAR Surveys of the MRL and Battures (WEST PLAQUEMINES)
Mississippi River Levee Profiles

NOTE: HPS = Hurricane Protection System

2012 100-year HSDRRS Condition

The 2012 100-year HSDRRS condition consists of the HSDRRS features that were in place at the time of Hurricane Isaac. Several survey datasets were utilized to develop the 2012 100-year HSDRRS condition and are listed in Table 2.2. Surveys were taken between 2006 and 2012.

An overview of the system features is shown in Figure 2.1, and described in detail below.

The height of the levees and floodwalls for the system is shown on Plate 1. The majority of the 2012 100-year HSDRRS levees, floodwalls, and structures have been constructed generally following the existing alignment of the LPV and WBV features that comprise the without 2012 100-year HSDRRS condition. The following is a list of new features that have been added and features at locations where the existing alignment has been modified.

Table 2.2 - Surveys used to determine 2012 100-year HSDRRS elevations

Survey Job Title
HSDRRS Line of Protection Survey (LP-01)
New Orleans District National Levee Foot Print Data Base Surveys
HSDRRS Line of Protection Survey (MRL)
New Orleans District National Levee Foot Print Data Base Surveys (NEW ORLEANS EAST)
HSDRRS Line of Protection Survey (LP-02)
IHNC EAST AND CHALMETTE LOOP - RIVER LOCK TO BAYOU BIENVENUE
HSDRRS Line of Protection Survey (LP-03)
Chalmette Loop HSP Levee Profiles
MISSISSIPPI RIVER LEVEES, LEVEE ENLARGEMENT STA 414 TO 570
New Orleans District National Levee Foot Print Data Base Surveys (ST CHARLES)
NEW ORLEANS LAKEFRONT FLOOD PROTECTION PROFILE
New Orleans District National Levee Foot Print Data Base Surveys (ST BERNARD)
Chalmette Loop HSP Levee Profiles
New Orleans District National Levee Foot Print Data Base Surveys (BELLE CHASSE)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (NEW ORLEANS) (ARCADIS)
NEW ORLEANS LAKEFRONT LPV 101-104
NCC, LPV-03d.2, St. Charles Parish, AP Runway Levee Ph II

IHNC EAST AND CHALMETTE LOOP - RIVER LOCK TO BAYOU BIENVENUE
HSDRRS LiDAR Data Review
Post-Katrina JALBTCX 2005 LiDAR
LPV Citrus Back Levee
ELMWOOD CANAL PUMP STATION #3
Jefferson Parish Lakefront Survey
LSER surveys for flood walls. (VARIOUS LOCATIONS)
LPV Citrus Back Levee
HSDRRS LiDAR Data Review
New Orleans District National Levee Foot Print Data Base Surveys
Jefferson Parish Lakefront NCC Survey - Additional Work at Bonnabel Blvd.
PUMPING STATION #2
HSDRRS LiDAR Data Review
STRUCTURE SURVEYS IN SUPPORT OF FLOOD FIGHT 2011
17TH STREET CANAL CLOSURE
Tie-In wall elevations
New Orleans District National Levee Foot Print Data Base Surveys
IHNC West River Lock to Seabrook

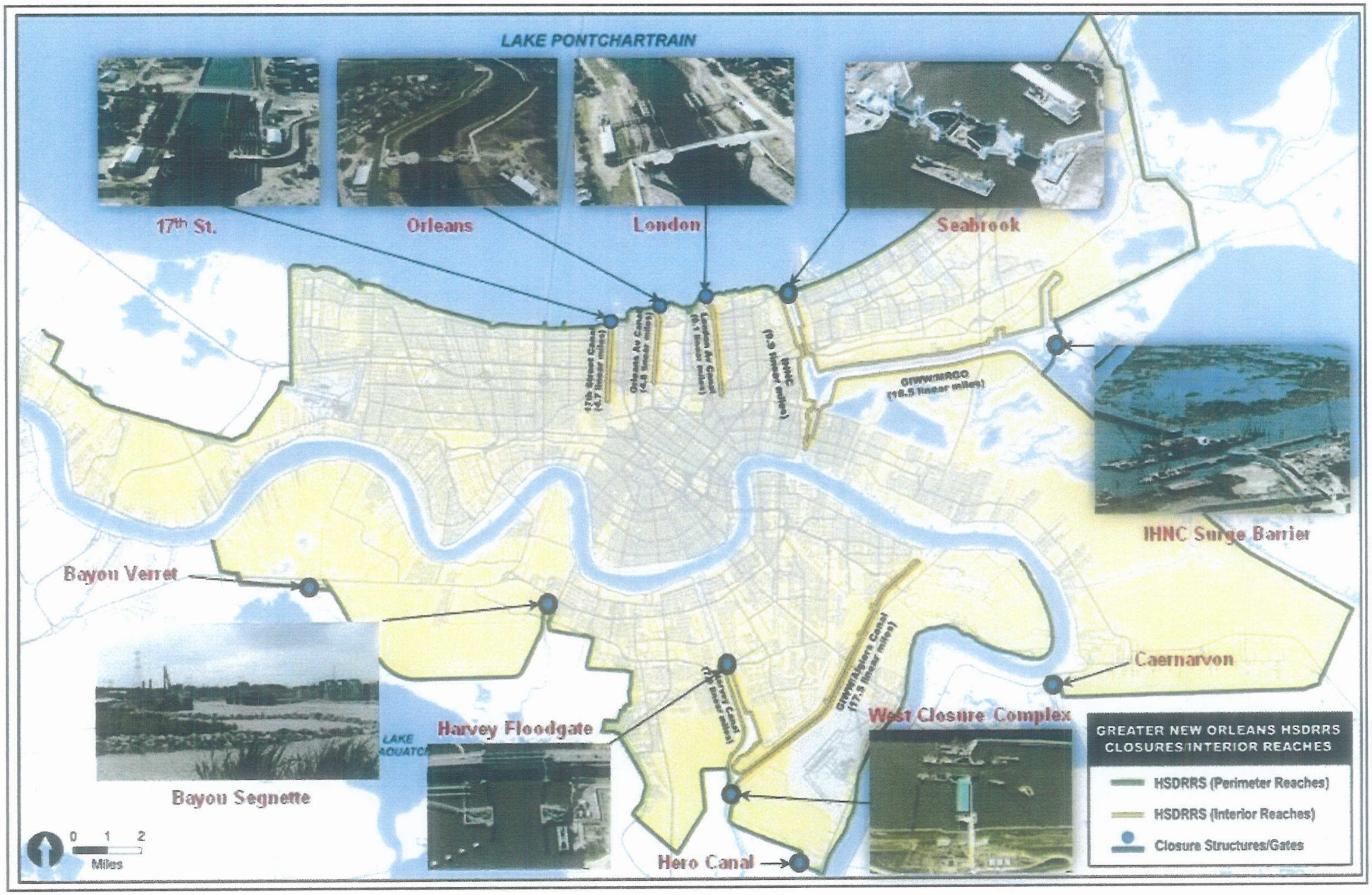

Figure 2.1. Major features of the 2012 100-year HSDRRS

IHNC System –The IHNC (Inner Harbor Navigation Channel) System is located in Orleans and St. Bernard Parishes in the state of Louisiana and contains several structures.

IHNC Surge Barrier - (HSDRRS Project Number IHNC-02) The IHNC Surge Barrier, a 10,000-foot long barrier, is located near the confluence of the Gulf Intracoastal Waterway (GIWW) and the Mississippi River Gulf Outlet (MRGO). The barrier consists of a bypass barge gate and a flood control sector gate at the GIWW, a vertical lift gate at Bayou Bienvenue, a braced concrete barrier wall across the MRGO and the Golden Triangle Marsh, and floodwalls on the north and south ends that tie into the risk reduction system in Orleans Parish and St. Bernard Parish, respectively. The surge barrier is also referred to as the Lake Borgne Surge Barrier.

Seabrook Gate Complex – (HSDRRS Project Number IHNC-01) The Seabrook Gate Complex is located at the confluence of the IHNC and Lake Pontchartrain in Orleans Parish. This complex consists of a sector gate and two lift gates.

At the time of Hurricane Isaac, all IHNC structures were in place (Figure 2.2).

Figure 2.2. IHNC Surge Barrier (top) and Seabrook Complex (bottom) in Orleans and St. Bernard Parishes.

The Outfall Canal Interim Closure Structures – Three interim closure structures (Figure 2.3) have been constructed on the London Avenue, 17th St, and Orleans Avenue Outfall canals near their confluence with Lake Pontchartrain in Orleans Parish. These structures restrict the entrance of Lake Pontchartrain storm surge into the outfall canals while allowing the water evacuated from the city via local pump stations to enter the lake. The structures consist of a series of panel gates and pumps. The rated pump capacity at the structures is: London Avenue 5,196 cubic feet per second (cfs); 17th St 9,794 cfs, and Orleans Avenue 2,200 cfs. Although these temporary structures provide the 100-year level of risk reduction to the three outfall canals, these structures will be replaced by permanent features of the HSDRRS (HSDRRS Project Number PCCP-01).

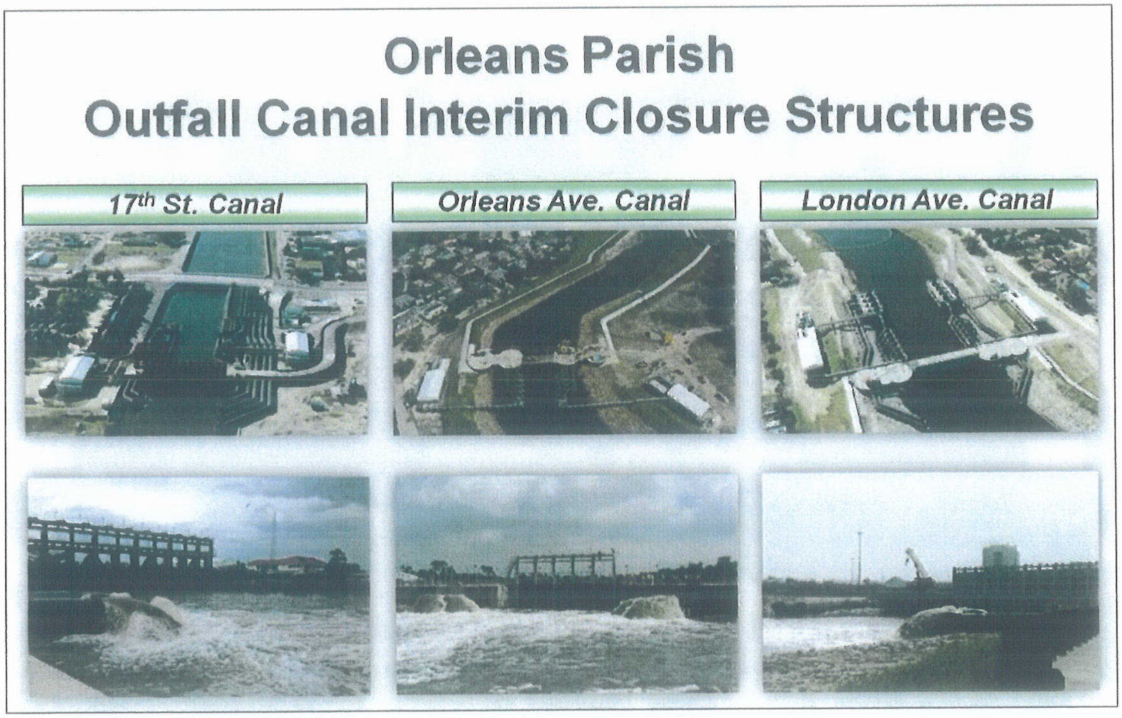

Figure 2.3. Interim Closure Structures. These temporary features provide the 100-year level of risk reduction at the mouths of the three outfall canals in Orleans Parish.

Caernarvon Floodwall and Gate – (HSDRRS Project Number LPV-149) A new floodwall has been constructed in the vicinity of the Caernarvon freshwater diversion structure, in St. Bernard and Plaquemines Parishes, with a sector gate, a road gate at Highway 39, a railroad gate, and drainage features to evacuate rainfall runoff from the area across the existing levee into St. Bernard Parish (Figure 2.4). This new alignment ties into the Mississippi River Levee just downriver from the Caernarvon Canal.

Figure 2.4. Aerial view of the Caernarvon Floodwall and Gate in St. Bernard and Plaquemines Parishes.

Eastern Tie-In – (HSDRRS Project Number WBV-09) The Eastern Tie-In, located on the west bank of the Mississippi River (Westbank) in Plaquemines Parish, has been constructed with the overall alignment shown in yellow and orange in Figure 2.5 below. In addition to levees and floodwalls, the project includes a navigable stop log gate on Hero Canal (WBV-09b), a swing gate for the Highway 23 closure (WBV-09c), and another swing gate for the adjacent railroad. Interior drainage from the WBV-09a and WBV-09c project components is routed to the WBV-09a pump station and gravity drain. The existing drainage to Hero Canal is handled by another pump station at the WBV-09b site. Since at the time of Hurricane Isaac, the swing gate for the Highway 23 closure was not installed, a temporary closure was placed at that location.

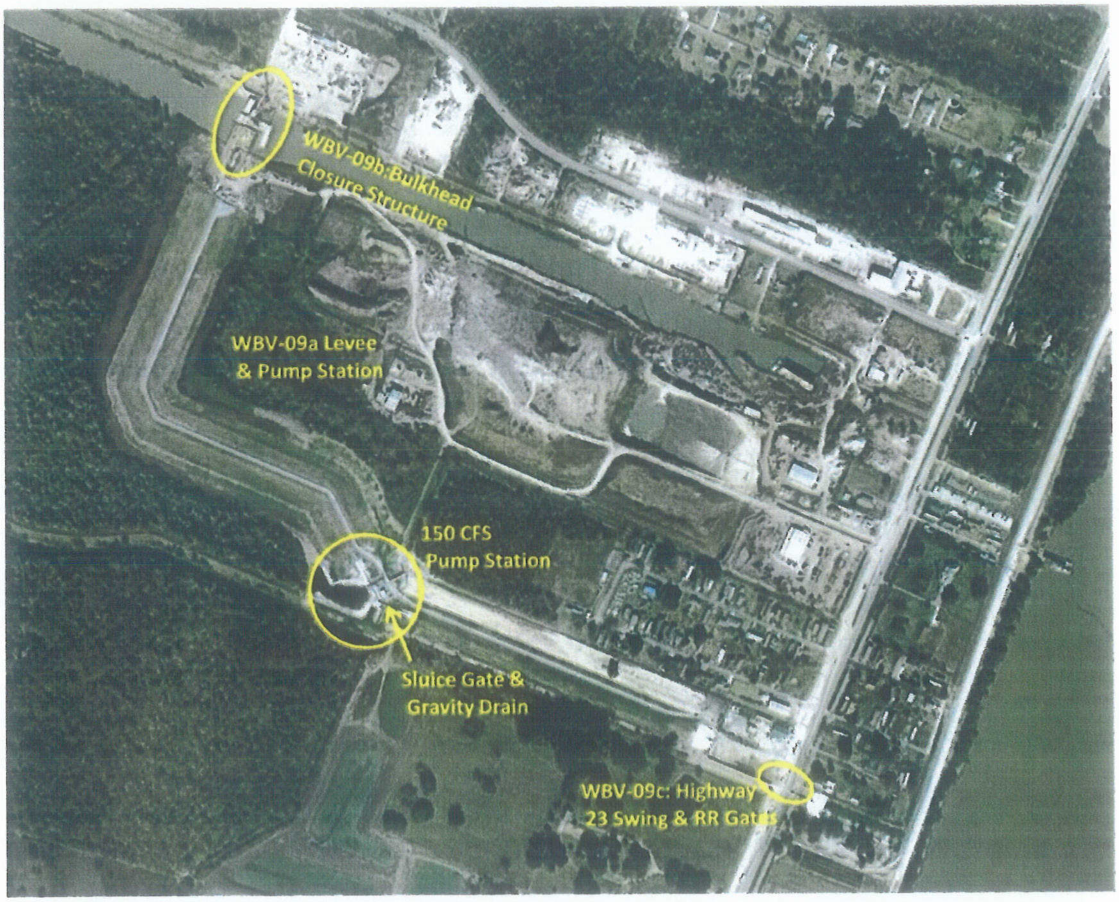

Figure 2.5. Aerial view of the Eastern Tie-In projects on the Westbank in Plaquemines Parish.

Harvey-Algiers System – The Harvey-Algiers System is located on the Westbank in Orleans, Jefferson, and Plaquemines Parishes and contains several structures added to the HSDRRS.

West Closure Complex. (HSDRRS Project Number WBV-90) The West Closure Complex (WCC) in Jefferson and Plaquemines Parishes (Figure 2.6) includes a sector gate and five gravity sluice gates that convey the flow in the GIWW when opened, and block storm surge when closed. The WCC also includes a 19,140 cfs pump station to pass the flow when the gates are closed.

The Estelle Water Control Structure on the Westbank in Jefferson Parish includes a pair of 8-foot by 8-foot sluice gates through the WCC floodwall that control the discharge from the Old Estelle Pump Station, allowing the flow to pass into the GIWW when opened, and blocking the flow (and storm surge) when closed.

The Harvey Canal Sector Gate (or Harvey floodgate, HSDRRS Project Number WBV-14) on the Westbank in Jefferson Parish (Figure 2.7) is a feature that was completed after Hurricane Katrina. The gate separates the southern end of the Harvey Canal from the northern end. For this analysis, it is assumed this gate is part of the pre-HSDRRS condition.

At the time of Isaac, all of the Harvey-Algiers System features were in place.

Figure 2.6. Aerial view of the West Closure Complex and Estelle Water Control Structure in Plaquemines and Jefferson Parishes.

Figure 2.7 Aerial view of the Harvey Sector Gate on the Westbank in Jefferson Parish.

Bayou Segnette Complex – (HSDRRS Project Number WBV-16) A new sector gate and pump station have been constructed in the Bayou Segnette area, on the Westbank in Jefferson Parish (Figure 2.8). The complex is operated to prevent high water stages from entering the Westwego area, to drain landside floodwaters, and to allow water traffic to proceed along Company Canal.

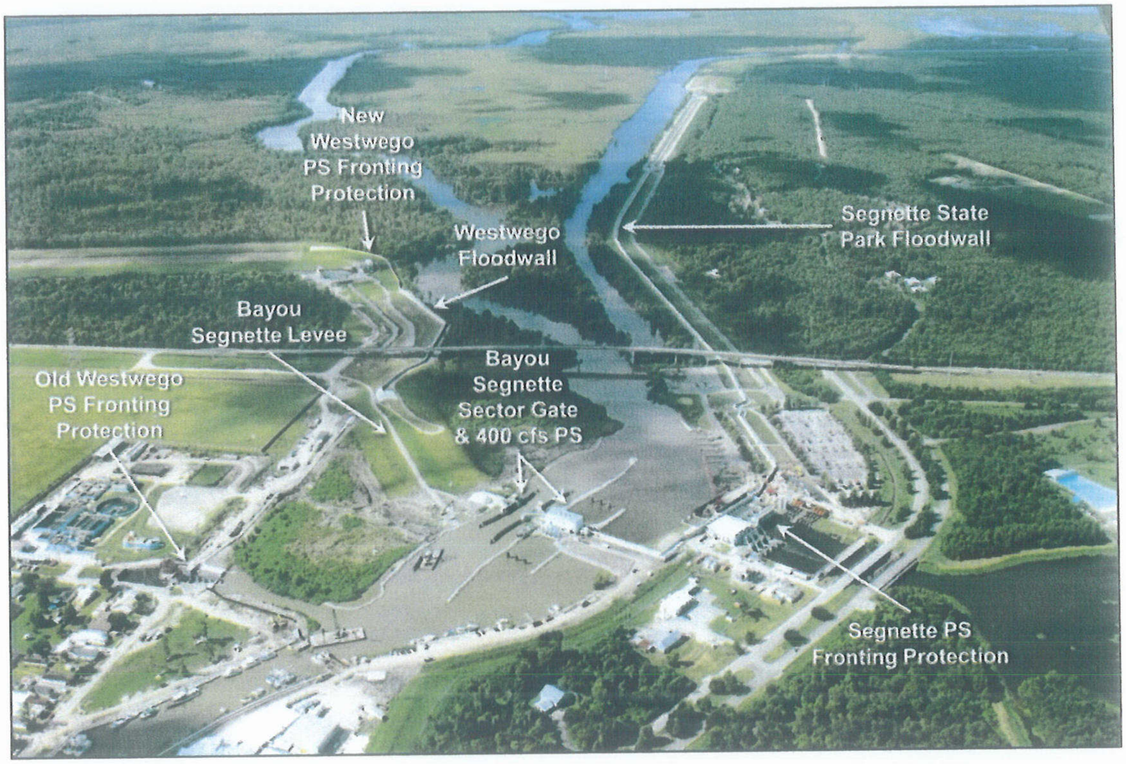

Figure 2.8. Aerial view of the Bayou Segnette Complex on the Westbank in Jefferson Parish.

Western Tie-In – (HSDRRS Project Number WBV-70-75) The Western Tie-In has been constructed with the overall alignment shown in Figure 2.9. In addition to levees and floodwalls, the project includes a gate at Highway 90 and a closure structure across the Bayou Verret Canal consisting of a 56- foot sector gate and a sluice gate structure with five 5-foot by 5-foot gates. At the time of Hurricane Isaac, the Highway 90 closure was not complete; Hesco baskets were placed across Highway 90 in advance of the storm event.

Figure 2.9. Aerial view of the Western Tie-In project features on the Westbank in St. Charles and Jefferson Parishes

Construction Closures and Interim Structures. At the time of Hurricane Isaac, construction was not complete on all of the 100-year HSDRRS features. Construction closures and interim structures were present in several locations, as shown on Figure 2.10.

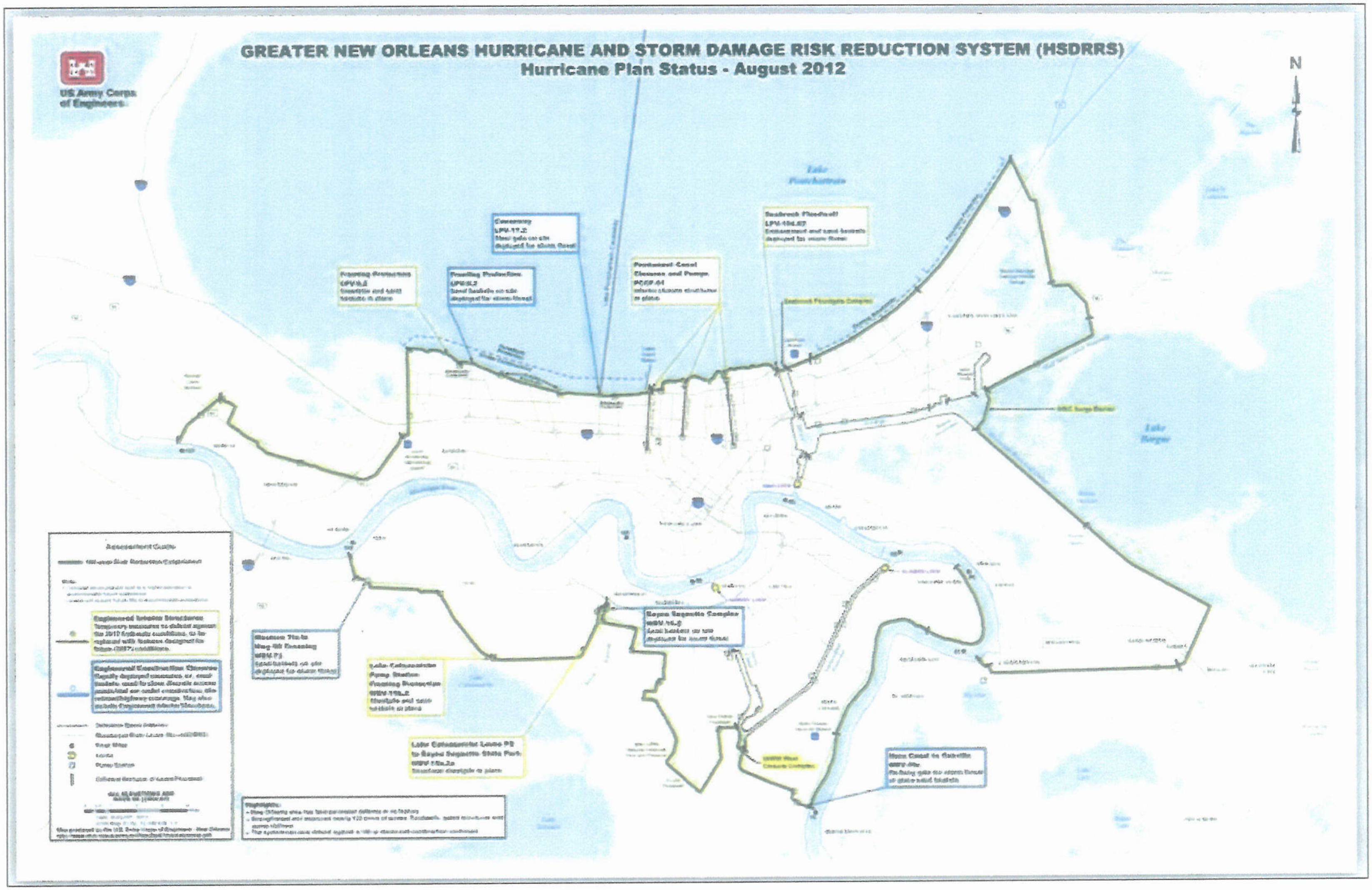

Figure 2.10 HSDRRS Construction Closures and Interim Structures in place during Hurricane Isaac.

3.0 HURRICANE ISAAC EVENT OVERVIEW

Chapter Summary

According to the Saffir-Simpson Hurricane Wind Scale, Hurricane Isaac was a minimal Category 1 hurricane, reaching maximum sustained wind speeds of approximately 80 miles per hour immediately before landfall. The extended duration of tropical force winds, the storm track and slow forward motion, the storm size, the high tide conditions and significant rainfall occurring at the same time as the maximum storm surge, resulted in large amounts of water being pushed into the coastal areas of the northern Gulf. In many cases, water levels exceeded those from more intense storms such as Hurricanes Katrina and Gustav.

3.1.1 Forward motion and track of the storm

Section 3.2.1 and 3.2.2 in this chapter highlight the storm chronology and synoptic history of Hurricane Isaac. The forward motion of Isaac was very slow. From the time Isaac entered the Gulf, winds from the south and east began filling coastal bays and inlets. The center of Isaac spent approximately 15 hours just off of the mouth of the Mississippi River, where eastern and southeastern winds pushed water into Barataria Basin, Breton Sound, the Pontchartrain Basin and Bay St. Louis areas. The storm then traveled slowly northward. For enclosed lakes and bays such as Lake Pontchartrain, the forward speed has an influence on the storm surge and timing of peak surge around the periphery of the lake. Like Hurricane Gustav, Hurricane Isaac approached Louisiana from the southeast, increasing the flow of surge waters into the coastal bays and inlets.

3.1.2 Rainfall

Section 3.2.3.1 provides details on the rainfall which occurred during Hurricane Isaac. The bulk of the storm total rainfall occurred between 0700 LST (1200 UTC) on 29 August and 1300 LST (1800 UTC) on 30 August. Storm total rainfall amounts of 8-12 inches were the norm across southeastern Louisiana and southern Mississippi. Many areas reported higher amounts with the highest measured total reported at Pascagoula, Mississippi of 22.20". Rainfall caused most rivers across the area to swell to above flood stage with new stage records set in southern Mississippi on the Wolf River at Landon and Gulfport, Mississippi and on East Hobolochitto Creek near Caesar, Mississippi. Over 10 inches of rainfall occurred at the Percy Quinn State Park with the bulk of the rain falling between 1300 LST (1800 UTC) 29 August and 0700 LST (1200 UTC) 30 August resulting in flooding along the Tangipahoa River. In southern Mississippi/Louisiana, 10-15 inches of rain that fell over the southern Pearl River and Bogue Chitto drove the rivers above major flood stage. Rainfall amounts of 8-15 inches occurred in the Lake Maurepas Basin adding to flooding that occurred from storm surge. The CoCoRaHS site at Reserve, Louisiana in St John the Baptist Parish recorded 14.84 inches. These rainfall amounts were greater than recent hurricanes, but comparable to Tropical Storm Allison in 2001.

3.1.3 Winds

As further detailed in Section 3.2.3.2, sustained tropical storm force winds were experienced over southeastern Louisiana and southern Mississippi for as long as 45 hours from midday on 28 August through midday 30 August. One station (Buras, LA) reported a sustained wind of Category 1 hurricane force. Peak gusts exceeding hurricane force were experienced at numerous locations across the area as well. The highest peak gust, 86 mph, was measured at Buras, Louisiana and with Boothville, Louisiana recorded a gust of 84 mph. Generally easterly winds were experienced over southeastern Louisiana and southern Mississippi from 26 August to the morning of 29 August. Winds then shifted so that they came from a southeastern to southern from 29 August through 31 August. Winds drove water toward the eastern shores of southeastern Louisiana and into Lake Pontchartrain causing elevated tide levels prior to Hurricane Isaac making landfall. After Isaac moved inland, winds shifted to the south, moving water from the north into the coastal areas. The southerly wind shift in the Mississippi Sound coincided with the timing of the peak surges along the western Mississippi coast. Because Isaac moved so slowly, the water surface gradient between Lake Borgne and Lake Pontchartrain caused the persistent filling action in Lakes Pontchartrain and Maurepas for several days before arrival of the main core winds of the hurricane.

Maximum winds were in the northeast quadrant of the storm, with strongest winds in the northeast and southeast quadrants. Isaac did not have a well-defined band of maximum winds wrapped around the eye. The observed maximum wind speed was a distance of 38 miles northeast of the eye. This ratio of radius to maximum winds is considered to be a relatively large value. In terms of hurricane intensity near landfall, Isaac had a central pressure of 975 mb and maximum observed wind speed of 75 mph, a magnitude at the lower limit of a Category 1 hurricane (74 mph) in terms of the Saffir-Simpson Hurricane Wind scale. These winds generated offshore waves generally in the range of 5-15 feet. However, the National Data Buoy Center's Station 42012 located at 30°03'55"N 87°33'19"W offshore from Orange Beach, Alabama on the east side of the storm track reported a peak wave height of 19.02 feet at approximately 1700 LST (2200 UTC) on 28 August.

3.1.4 Water Level Heights

Section 3.2.3.4 shows that tide levels were already high in coastal Louisiana due to a period of easterly winds prior to Hurricane Isaac entering the Gulf of Mexico, with Lake Pontchartrain almost 1 foot above predicted tide levels. Water levels began to rise from Hurricane Isaac around midnight on 28 August and continued to rise until late on 29 August.

Characteristics of the surface winds and the storm tracks help explain differences in storm surge throughout the Louisiana and Mississippi coastal areas. There is extensive documentation of high water marks and surge elevations elsewhere in this report, however, generally, surge elevations ranged from 5-7 feet on the West Bank near Ama, Louisiana to 12-14 feet in the Caernarvon area and in the vicinity of the new IHNC Barrier. Data from USGS sensors indicate that peak water levels at Braithwaite reached 13.5 to 13.7 feet, NAVD88 during Isaac, while preliminary high water marks collected by the USGS after Isaac indicated 5.1 and 4.9 feet at Lafitte, Louisiana.

The filling of Lakes Pontchartrain and Maurepas is controlled by the water level in Lake Borgne and western Mississippi Sound. As long as the water level in the sound exceeds the water level in the lakes, filling of the lakes occurs. Water level data from the NOAA gage at Bay Waveland Yacht Club in Mississippi was evaluated during both Hurricanes Isaac and Gustav. The water level in western Mississippi Sound remained high for a much longer period of time during Isaac than during Gustav. This is primarily due to the much slower forward speed of Isaac compared to Gustav. The peak water level reached about 9.5 feet NAVD88 during Isaac; however, the water level exceeded 6 feet NAVD88 for about 24 hours, and exceeded 4 feet NAVD88 for about 48 hours. During Gustav, the peak water level reached 10.5 feet NAVD88; however, it only exceeded 6 feet NAVD88 for about 12 hours and 4 feet NAVD88 for 24 hours. This difference led to an increase in the filling of the lakes for Isaac compared to Gustav.

In addition to the wind-driven storm surge, heavy rainfall was a contributing factor to peak water levels throughout southeastern Louisiana and southern Mississippi. Some gages initially rose as a result of storm surge, then received a second rise due to rainfall

Graphs of river gage data presented in Section 3.2.3.5 show that storm surge from Hurricane Isaac propagated up the Mississippi River as far at the Red River Landing gage at river mile 302.5.

3.1.5 Comparison of Isaac to other Events

Due to its storm track, slow forward motion, large size and the location of maximum winds, Hurricane Isaac resulted in higher levels of storm surge and higher rainfalls in many locations in coastal Louisiana and Mississippi than other recent storms. Section 3.3 of this chapter provides detailed information on the storm tracks, the effects of wind on the storm surge, and rainfall patterns for Hurricanes Isaac, Katrina and Gustav. The wind conditions that acted to move water into places like Barataria basin during Hurricane Isaac were very different than those experienced in other storms, such as Hurricane Katrina. Section 3.4 compares Isaac to a suite of synthetic storms that was defined for simulation in the various risk reduction studies conducted by USACE in coastal Louisiana and Mississippi following Hurricane Katrina. The combination of Hurricane Isaac's intensifying as it approached the coast, halting of forward motion and drifting near landfall, extremely large size, and slow forward speed made it unlike any storm in the synthetic storm suite.

Hurricane Isaac Data

3.1.6 Storm Chronology

Hurricane conditions were experienced over southeastern Louisiana and southern Mississippi from midday 28 August through midday 30 August. The eastern shores of southeastern Louisiana experienced tropical storm force winds for nearly 2 days due to the slow movement of Isaac (Table 3.1). Rainfall amounts of 8-12 inches were the norm over the region with some areas recording storm totals exceeding 20 inches.

Table 3.1 Hurricane Isaac Preliminary Best Track Information based on NHC advisories where LST is Local Time in New Orleans. TD=Tropical Depression, TS=Tropical Storm, HU=Hurricane.

Date/Time (UTC)(2012)	Date/Time (LST)(2012)	North Latitude	West Longitude	Maximum Sustained wind speed (mph)	Central Pressure (mb)	Stage
21 Aug 0900	21 Aug 0400	15.2	51.2	35	1007	TD
21 Aug 1200	21 Aug 0700	15.2	52.0	35	1007	TD
21 Aug 1500	21 Aug 1000	15.1	52.3	35	1008	TD
21 Aug 1800	21 Aug 1300	15.3	53.2	35	1005	TD
21 Aug 2100	21 Aug 1600	15.4	53.9	40	1006	TS
22 Aug 0000	21 Aug 1900	15.4	54.8	40	1006	TS
22 Aug 0300	21 Aug 2200	15.6	55.6	40	1006	TS
22 Aug 0600	22 Aug 0100	15.5	56.5	45	1003	TS
22 Aug 0900	22 Aug 0400	15.5	57.3	45	1003	TS
22 Aug 1200	22 Aug 0700	15.9	58.5	45	1006	TS

22 Aug 1500	22 Aug 1000	15.9	59.3	45	1006	TS
22 Aug 1800	22 Aug 1300	15.9	60.4	45	1004	TS
22 Aug 2100	22 Aug 1600	16.0	61.2	45	1004	TS
23 Aug 0000	22 Aug 1900	15.8	62.2	45	1004	TS
23 Aug 0300	22 Aug 2200	15.8	63.0	45	1003	TS
23 Aug 0600	23 Aug 0100	15.3	63.5	40	1004	TS
23 Aug 0900	23 Aug 0400	15.3	64.0	40	1004	TS
23 Aug 1200	23 Aug 0700	15.4	64.8	40	1003	TS
23 Aug 1500	23 Aug 1000	15.6	65.4	40	1003	TS
23 Aug 1800	23 Aug 1300	15.9	66.4	40	1004	TS
23 Aug 2100	23 Aug 1600	16.0	67.1	40	1003	TS
24 Aug 0000	23 Aug 1900	16.5	68.0	45	1002	TS
24 Aug 0300	23 Aug 2200	16.7	68.7	45	1001	TS
24 Aug 0600	24 Aug 0100	16.2	69.6	45	1000	TS
24 Aug 0900	24 Aug 0400	16.1	70.0	45	1000	TS
24 Aug 1200	24 Aug 0700	15.9	70.4	60	1000	TS
24 Aug 1500	24 Aug 1000	16.3	70.8	60	1000	TS
24 Aug 1800	24 Aug 1300	16.7	71.3	65	995	TS
24 Aug 2100	24 Aug 1600	17.2	71.9	65	994	TS
25 Aug 0000	24 Aug 1900	17.3	72.0	65	992	TS
25 Aug 0300	24 Aug 2200	17.7	72.5	70	990	TS
25 Aug 0600	25 Aug 0100	18.1	72.7	65	991	TS
25 Aug 0900	25 Aug 0400	19.0	73.3	60	992	TS
25 Aug 1200	25 Aug 0700	19.7	73.7	60	998	TS
25 Aug 1500	25 Aug 1000	20.1	74.6	60	998	TS
25 Aug 1800	25 Aug 1300	20.8	75.3	60	997	TS
25 Aug 2100	25 Aug 1600	21.3	76.0	60	997	TS
26 Aug 0000	25 Aug 1900	21.7	76.7	60	997	TS
26 Aug 0300	25 Aug 2200	22.1	77.2	60	997	TS
26 Aug 0600	26 Aug 0100	22.8	78.2	60	995	TS
26 Aug 0900	26 Aug 0400	23.1	79.0	65	995	TS
26 Aug 1200	26 Aug 0700	23.5	80.0	65	995	TS
26 Aug 1500	26 Aug 1000	23.9	80.8	65	995	TS
26 Aug 1800	26 Aug 1300	23.9	81.5	60	992	TS
26 Aug 2100	26 Aug 1600	24.2	82.3	60	992	TS
27 Aug 0000	26 Aug 1900	24.0	82.5	65	992	TS
27 Aug 0300	26 Aug 2200	24.2	82.9	65	993	TS
27 Aug 0600	27 Aug 0100	24.9	83.7	60	990	TS
27 Aug 0900	27 Aug 0400	25.2	84.2	65	990	TS
27 Aug 1200	27 Aug 0700	25.8	84.8	65	987	TS
27 Aug 1500	27 Aug 1000	26.1	85.3	65	988	TS
27 Aug 1800	27 Aug 1300	26.1	85.9	70	984	TS
27 Aug 2100	27 Aug 1600	26.4	86.2	70	981	TS
28 Aug 0000	27 Aug 1900	26.7	86.5	70	981	TS
28 Aug 0300	27 Aug 2200	27.1	87.0	70	979	TS
28 Aug 0600	28 Aug 0100	27.4	87.7	70	978	TS
28 Aug 0900	28 Aug 0400	27.5	88.1	70	977	TS
28 Aug 1200	28 Aug 0700	27.8	88.2	70	976	TS
28 Aug 1500	28 Aug 1000	28.1	88.5	70	976	TS

28 Aug 1620	28 Aug 1120	28.1	88.6	75	975	HU
28 Aug 1800	28 Aug 1300	28.5	88.9	75	975	HU
28 Aug 2100	28 Aug 1600	28.7	89.2	80	975	HU
29 Aug 0000	28 Aug 1900	28.9	89.5	80	968	HU
29 Aug 0300	28 Aug 2200	29.0	89.7	80	968	HU
29 Aug 0600	29 Aug 0100	29.0	90.1	80	968	HU
29 Aug 0900	29 Aug 0400	29.2	90.5	80	969	HU
29 Aug 1200	29 Aug 0700	29.4	90.5	80	970	HU
29 Aug 1500	29 Aug 1000	29.6	90.7	75	972	HU
29 Aug 1800	29 Aug 1300	29.8	90.8	70	974	TS
29 Aug 2100	29 Aug 1600	30.0	91.1	70	975	TS
30 Aug 0000	29 Aug 1900	30.1	91.1	60	980	TS
30 Aug 0300	29 Aug 2200	30.3	91.2	60	980	TS
30 Aug 0600	30 Aug 0100	30.6	91.5	55	982	TS
30 Aug 0900	30 Aug 0400	30.9	91.6	45	983	TS
30 Aug 1200	30 Aug 0700	31.3	92.0	45	985	TS
30 Aug 1500	30 Aug 1000	31.7	92.1	40	987	TS
30 Aug 1800	30 Aug 1300	32.2	92.4	40	992	TS
30 Aug 2100	30 Aug 1600	32.7	92.6	35	995	TD
31 Aug 0300	30 Aug 2200	33.5	93.0	30	998	TD
31 Aug 0900	31 Aug 0400	34.7	93.9	25	999	TD
31 Aug 1500	31 Aug 1000	35.6	94.1	25	1003	TD
31 Aug 2100	31 Aug 1600	37.3	93.8	25	1004	TD
01 Sep 0300	31 Aug 2200	38.3	93.5	25	1005	TD
01 Sep 0900	1 Sep 0400	38.5	93.0	25	1004	TD

Figure 3.1 Gulf of Mexico track for Hurricane Isaac 27 August through 30 August.

3.1.6.1 Synoptic History

Hurricane Isaac began as Tropical Depression Nine which formed from a tropical wave on 21 August at 0400 LST (0900 UTC) approximately 715 miles east of the Leeward Islands of the eastern Caribbean. Air Force reconnaissance aircraft investigating the tropical depression that afternoon found that Tropical Depression Nine had intensified into Tropical Storm Isaac about 500 miles east of Guadeloupe. Shear and dry air inhibited intensification during the next several days with the system passing through the Leeward Islands (near Guadeloupe) as a minimal tropical storm the afternoon of 22 August. Isaac became a little better organized and strengthened to a strong tropical storm just prior to moving across southwestern Haiti during the early morning hours of 25 August. The center of Isaac avoided significant land interaction from the mountains of Hispaniola and eastern Cuba on 25 August emerging into the southwestern Atlantic during the evening. Tropical Storm Isaac continued to move west-northwest, passing just south of Key West, FL during the day of 26 August; reaching the Gulf of Mexico on the evening of 26 August.

While moving slowly west-northwest through the Gulf of Mexico on 27/28 August (Figure 3.5), Tropical Storm Isaac remained a poorly organized system with a very large wind field envelope. The central core of the tropical storm remained broad due to shear and did not begin to consolidate until hours prior to landfall. Isaac finally intensified into a Category 1 hurricane at 1120 LST (1620 UTC) on 28 August approximately 75 miles south-southeast of the mouth of the Mississippi River.

Hurricane Isaac made landfall at 1845 LST (2345 UTC) 28 August just to the west of the mouth of the Mississippi River. Steering currents at landfall were very weak and the center of Isaac actually drifted back over water for several hours later that evening with the center making a second landfall near Port Fourchon, LA around 0115 LST (0615 UTC) on Wednesday 29 August. Isaac moved very slowly northwestward during the day of 29 August, causing a prolonged period of strong east to east/southeast winds along the eastern shores of southeastern Louisiana, across the Lake Pontchartrain Basin, and along the Mississippi coast.

These persistent tropical storm force winds, very slow forward motion, and the broadness of the wind field in Isaac were main contributing factors in producing much higher than normal storm surge values than for a typical Category One hurricane. During the afternoon of 30 August, Tropical Storm Isaac had gained sufficient latitude (west of New Orleans/south of Baton Rouge) to become influenced by the Western Atlantic ridge and began to move quicker northwest across Louisiana, entering Arkansas around 1700 LST (2200 UTC) 30 August.

The center of Isaac moved northward during the next several days producing moderate to locally heavy rains across Arkansas, Missouri and Illinois. On 1 September, the remnants of Isaac were absorbed by a cold front with the system moving through the Ohio Valley producing moderate to locally heavy rains during its passage.

3.1.7 Meteorological Data

3.1.7.1 Storm Total Rainfall Summary

Storm total rainfall amounts of 8-12 inches were the norm across southeastern Louisiana and southern Mississippi. Many areas reported higher amounts with the highest measured total reported at Pascagoula, MS of 22.20 inches. Rainfall caused most rivers across the area to swell to above flood stage with new stage records set in southern Mississippi on the Wolf River at Landon and Gulfport and on East Hobolochitto Creek near Caesar. Over 10 inches of rainfall occurred at the Percy Quinn State Park with the bulk of the rain falling between 1300 LST (1800 UTC) 29 August and 0700 LST (1200 UTC) 30 August resulting in flooding along the Tangipahoa River. In southern Mississippi/Louisiana, 10-15 inches of rain over the southern Pearl River and Bogue Chitto drove the rivers above major flood stage. Rainfall amounts of 8-15 inches occurred in the Lake Maurepas Basin adding to flooding that occurred from storm surge. The CoCoRaHS rain gage site at Reserve, Louisiana in St John the Baptist Parish recorded 14.84 inches.

Table 3.2 is condensed from data provided by the National Weather Service (NWS) River Forecast Center in Slidell and shows measured rainfall data at locations along the river systems in southeastern Louisiana and southern Mississippi. From the data it is noted that the bulk of the storm total rainfall occurred between 0700 LST (1200 CTU) on 29 August and 1300 LST (1800 UTC) on 30 August. The Hydrometeorological Prediction Center in their document pertaining to storm total rainfall with respect to duration located at **http://www.hpc.ncep.noaa.gov/tropical/rain/tcduration.html** states that 75-80% of the average tropical cyclone rainfall occurs during a 30 hour period. The selected 30-hour period produced 81.1% of Isaac's storm total rainfall over southern Mississippi and southeastern Louisiana.

Table 3.2 Hurricane Isaac Mean Aerial Precipitation. This table provides total rainfall data in inches provided for river gages by NWS River Forecast Center in Slidell and rainfall totals for the period 0700 LST (1200 UTC) 29 August-1300 LST (1800 UTC) 30 August.

Location	Storm Total Rain 8/28-8/30	Rainfall 8/29 0700 LST 8/30-1300 LST
Amite River at Darlington	8.63	7.92
Amite River at Denham Springs	7.13	6.25
Amite River at Bayou Manchac	8.75	7.14
Amite River at Port Vincent	12.73	9.97
Comite River at Olive Branch	6.33	5.93
Comite River at Zachary	6.53	6.05
Tickfaw River at Liverpool	9.9	8.93
Tickfaw River at Montpelier	9.56	8.42
Tickfaw River at Holden	12	10.34
Tangipahoa River at Osyka	10.88	9.87
Tangipahoa River at Kentwood	10.71	9.52
Tangipahoa River at Amite	10.51	9.38
Tangipahoa River at Robert	10.79	9.43
Tchefuncte River at Folsom	10.36	9.24
Tchefuncte River at Covington	10.32	8.69
Bogue Falaya at Boston Street	10.32	8.41
Pearl River at Bogalusa	11.62	9.42
Bogue Chitto River at Tylertown	9.98	8.75
Bogue Chitto near Franklinton	11.07	9.75
Bogue Chitto near Bush	10.64	9.27
Pearl River at Pearl River	10.52	8.63
Landon	12.12	8.97
Wolf River at Gulfport	11.7	8.76
Wortham	12.92	8.91
Biloxi River at Lyman	12.59	8.74
Tchoutacabouffa River near D'Iberville	12.2	8
Mississippi River at Red River Landing	4.79	4.25
Mississippi River at Baton Rouge	5.03	4.71
West Hobolochitto Creek near McNeil	11.09	8.81
Hobolochitto Creek at Carriere	11.34	8.83

The heaviest rainfall occurred mostly over southern Mississippi which remained in a strong outer band of Isaac for nearly two days. Generally, rainfall totals decreased slowly as one moved from east to west with some exceptions such as the gage in New Orleans at Carrollton which recorded 20.66 inches. Figure 3.6 was derived from data contained in the Post Tropical Cyclone Report issued on 13 September by the NWS Slidell weather forecast office and from the National Weather Service storm total rainfall graphic.

Hurricane Isaac produced high rainfall totals throughout southeastern Louisiana and southern Mississippi due to the very slow movement after landfall and its angle of approach. Historically, Isaac was much wetter over a larger area than Katrina (2005), Gustav (2008), Juan (1985), Camille (1969), and Betsy (1965). Tropical Storm Allison (2001) produced slightly more rainfall than Isaac over especially the western portions of southeastern LA. Storm total rainfall of 8-12 inches with locally higher amounts to 20+ inches caused numerous rivers to exceed major flood stage and added to the flooding caused by storm surge.

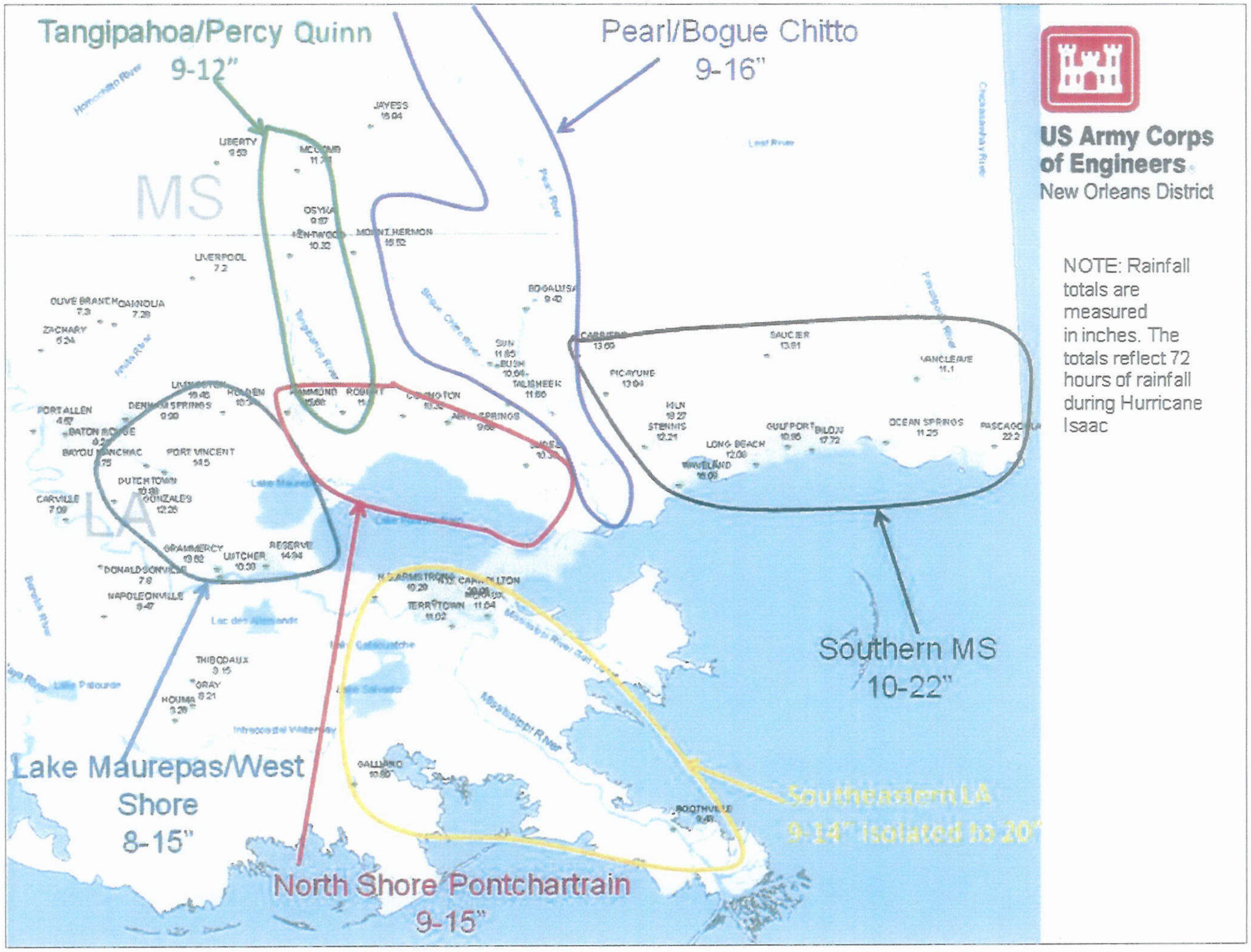

Figure 3.2 Total rainfall for Hurricane Isaac. Graphic was derived from NWS rainfall observational data. Areas are divided into sub-basins of maximum impacts in the region. The sub-basin delineation was derived for communication purposes.

Figures 3.3 and 3.4 show that Bayou Manchac in the Lake Maurepas area and the Tchefuncte River at Madisonville on the north shore of Lake Pontchartrain experienced a significant rise prior the heaviest rainfall occurring. Then these sites showed a secondary rise as a direct result of rainfall. The gages located on rivers displayed in Figures 3.3 and 3.4 show a response primarily due to rainfall over the river basin, although this water drained to the coastal areas as well.

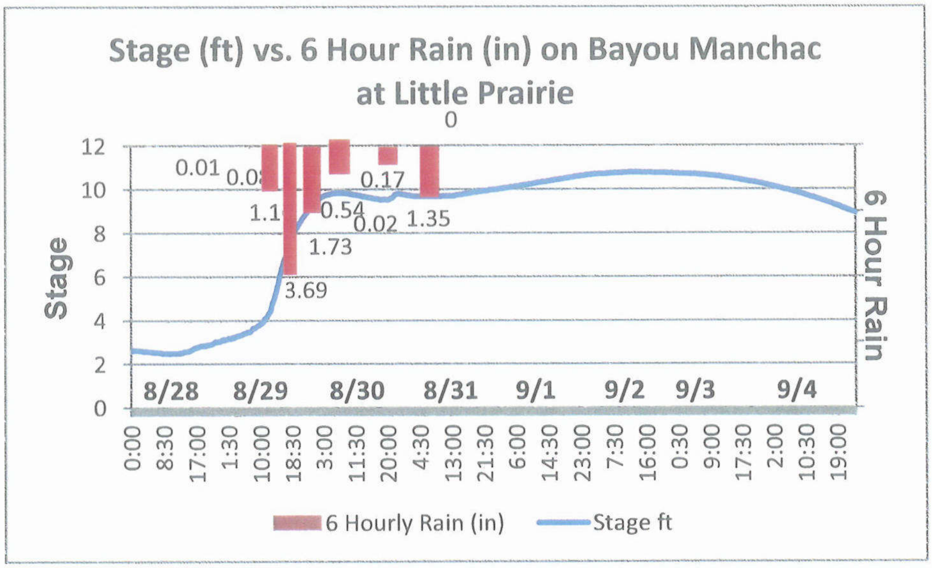

Figure 3.3 Stage vs. 6-Hour Rainfall on Bayou Manchac at Little Prairie, LA. This figure illustrates that at this location the storm surge was building prior to significant local rainfall. Stage datum: NAVD88.

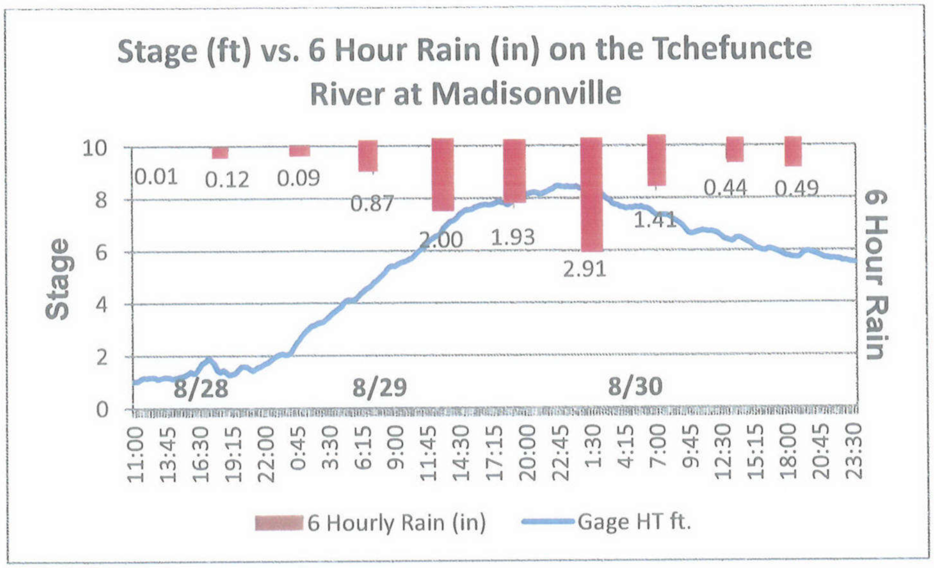

Figure 3.4 Stage vs. 6-Hour Rainfall on the Tchefuncte River at Madisonville, LA. This figure illustrates that at this location the storm surge was building prior to significant local rainfall. Gage height, no datum.

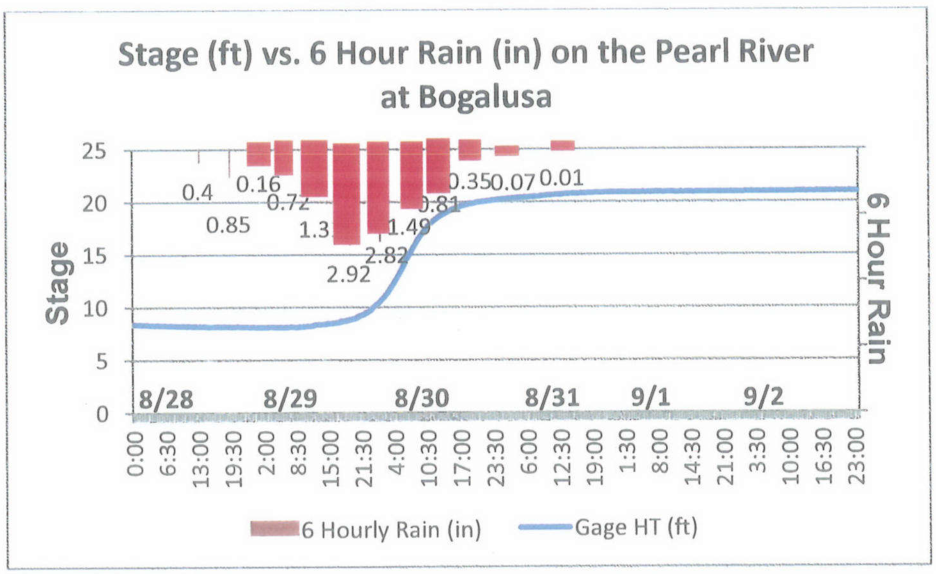

Figure 3.5 Stage vs. 6-Hour Rainfall on the Pearl River at Bogalusa, LA. This figure illustrates that at this location the water level increase was primarily due to significant local rainfall. Gage height, gage zero is 54.64 ft NAVD88.

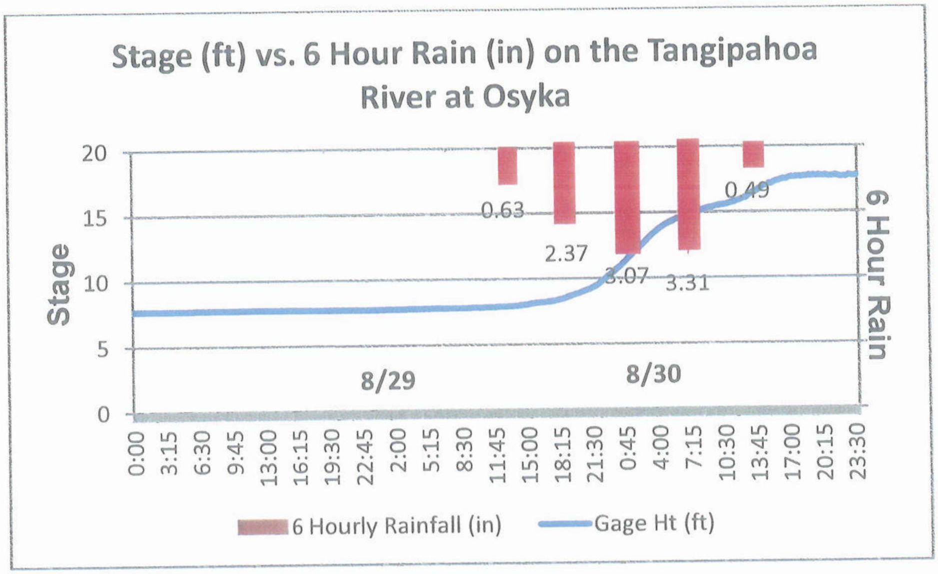

Figure 3.6 Stage vs. 6-Hour Rainfall on the Tangipahoa River at Osyka, LA. This figure illustrates that at this location the water level increase was primarily due to significant local rainfall. Gage height, no datum.

3.1.7.2 Wind Summary

Tropical storm force winds were experienced over southeastern Louisiana and southern Mississippi for as long as 45 hours from midday on 28 August through midday 30 August. One station (Buras, LA) reported a sustained wind of Category 1 hurricane force. Peak gusts exceeding hurricane force were experienced at numerous locations across the area as well. The highest peak gust, 86 mph, was measured at Buras, Louisiana; additionally Boothville, Louisiana recorded a gust of 84 mph. Table 3.3, compiled from the Post Tropical Cyclone Report issued by the NWS's Slidell office on 13 September, depicts the maximum sustained wind direction/speed at various locations in Louisiana and Mississippi. Peak gusts at the locations are included as well as anemometer heights. Data has been adjusted from the NWS report to convert knots to mph and UTC to LST.

Since Isaac was a very slow moving hurricane with a large wind field, the duration of tropical storm force winds was a key factor in producing higher than normal surges when compared to a typical Category 1 hurricane. On the Mississippi Sound at Grand Pass (Figure 3.7), tropical storm force winds were recorded from 0615 on 28 August through 0345 on 30 August, a total of 45 hours. It should be noted that winds of 10-30 mph generally from the east occurred from the morning of 26 August to the onset of tropical storm force winds. In fact, east to southeast winds blew from 26 August into the morning of 29 August before shifting to southerly from mid morning on the 29 August through 31 August. The extended duration of generally easterly winds